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Treatment of Water With Boiler Compounds

Chemical Engineering

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TREATMENT OF WATER WITH BOILER COMPOUNDS

BY

WILLIAM CHRISTOPH MARTI

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE

IN CHEMICAL ENGINEERING

IN THE

COLLEGE OF SCIENCE

OF THE

UNIVERSITY OF ILLINOIS

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June 1, 1909

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

William Christoph Marti

ENTITLED Treatment of Water with Boiler Compounds.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science

in Chemical Engineering.

Edward Barlow
Instructor in Charge.

APPROVED: W^m A. Noyes.

HEAD OF DEPARTMENT OF Chemistry

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INTRODUCTION.

One phase in nearly every industry in which water plays an important part is that in which it is used for the production of steam, either for heating or for the development of motive power. Many difficulties enter into this process. The total conversion of all the heat into steam is the ideal result desired. Much of the heat is lost by radiation, but by far the greater amount of it is lost in the boiler proper. In some waters this great loss is due partly to the formation of scale on the inside of the boiler. Serious losses in boiler efficiency are due to corrosion and foaming. In the following pages we consider these three phases of the action of water in boilers.

SCALING.

Scale is the deposite formed on the inside of the boiler, and on the inside of the tubes in a water tube boiler, and the outside of the tubes in a fire tube boiler. It is caused by impurities in the water that are left behind as the water evaporates.

If the water used in a boiler were perfectly pure there would be no trouble due to scaling. All natural waters contain more or less solid matter in solution, or mixed with it mechanically and held in suspension. The most troublesome substances found in boiler waters are salts of magnesium, and calcium. Carbonates and sulphates of calcium and magnesium are the chief producers of scale.

It would appear that a few grains of solid matter would not have much effect in a large boiler, but it is not long before these few grains become tons. Taking three gallons per hour as a fair amount of water to be evaporated to produce the steam for

developing one horse power of work, an engine of 100 HP. will require 3000 gallons of water to be evaporated in a days run of 10 hours. Supposing that the average amount of solid matter in waters is 15 grains per gallon or 6.5 pounds in the 3000 gallons. This amounts to 2cwt. a month or a little over a ton a year. If this consists of the carbonates and sulphates of calcium and magnesium, the most of the residue remains in the boiler as scale, and the non-conducting power of this material is the source of much trouble and loss.

Since it requires about 1/2 ton of coal to evaporate 1000 gallons of water the cost of bringing this about, taking the average price of the coal used as $3.00 a ton, would be $1.50. But when scale collects the amount of heat transferred to the water becomes less and less, and in order to supply the required amount of steam more heat must be supplied and consequently more coal must be burned. The following table gives an example of the waste involved.*

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*Water Softening - Collet - page 18.

	Per cent Waste			
	10 Cost	15 Cost	20 Cost	25 Cost
With coal at $ 1.95 per ton	$ .100	$ .145	$ .192	$ .241
" " " 2.43 " "	.121	.180	.241	.302
" " " 2.92 " "	.145	.217	.286	.360
" " " 3.41 " "	.168	.252	.337	.420
" " " 3.89 " "	.192	.288	.384	.482

The following figure gives the thickness and comparative resistance to the transmission of heat, of the boiler plate and its coating of scale.*

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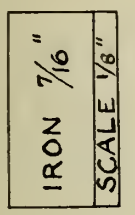
*Water Softening - Collet - page 18.



Actual Thickness.

IRON	SCALE
1	5
=$.04	=$.21 per 1000

Comparative resistance and Cost.

To the above losses must be added the cost of frequently cleaning out the boiler. Many boiler explosions have been directly caused by the formation of scale on the inside. The scale keeps the plate from becoming properly cooled, it becomes overheated and soft, and the pressure of the steam inside is able to force an opening the outcome of which is evident to every one.

The scaling matter in water varies greatly with the character of the soil and rock through which the water passes. The substances which go to make up the scale in a boiler are also the ones which go to make up that property of water known as hardness.

Hardness is divided into two classes:- Temporary and Permanent. Temporary hardness is due to the presence of carbonates, which substances form the soft scales. Permanent hardness is due to sulphates, chlorides and nitrates(mineral acid hardness). Sulphates of magnesium and calcium form a very hard scale. They are the least desirable as constituents of a boiler water.

The amount of trouble caused by a certain thickness of scale depends largely upon the substances in solution. About 1/4 inch of scale is the average amount that causes trouble, but in some of the Eastern waters because of the character of the scale, 1/16 inch of scale is noticeable. A thin coating of scale is thought by many to be an advantage, since it protects the plates from corrosion, but it may aid this latter action rather than hinder it, because of pitting under the scale. The following table* shows the number of

*Report of Com., Am. Ry.Eng.& Maintenance of Way Ass. Bull. 83,p 41.

hours service required to form 1/16 inch scale for various amounts of incrusting matter.

Pounds of Incrusting Solids per 1000 gallons of water.	1	2	3	4	5	6
Hours of Service to Accumulate 1/16 inch scale.	781	391	260	195	156	130

CORROSION.

Corrosion is the eating away of the metal portions of the boiler; it is caused by the presence of acids or acid forming substances in the water. Dissolved oxygen may also cause corrosion by the process known as rusting.

Free carbonic acid causes corrosion. There is always greater rusting at the point at which the water enters the boiler,*

*Exam. of Water for San. and Tech. Purposes - Leffman - page 120.

since there the gases are driven out of solution and immediately

attack the metal. The corrosive action of oxygen and carbonic acid is especially noticeable in waters that are comparatively pure, such as those derived from mountain springs. This was repeatedly observed by Dr. William Bean in examining waters used by the Baltimore and Ohio railroad.

Magnesium chloride in considerable quantity is harmful. This salt reacts with water at high temperatures with the formation of the hydroxide and hydrochloric acid. The free acid corrodes the iron plates of the boiler. Allen* remarks that the presence of a

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*Exam. of Water for San. and Tech. Purposes - Leffman - page 121.

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certain amount of common salt prevents this composition due to the formation of a more stable double salt.($MgCl_2$,NaCl,$6H_2O$)

Corrosion is probably the most destructive of the forces which tend to shorten the life of a boiler. The three forms of corrosion occurring in a boiler are:- Uniform corrosion, Pitting, and Grooving. In uniform corrosion large areas of the plate are eaten away. In pitting the plates are in spots indented with holes, in most cases formed under a coating of scale. The following figure shows an example of pitting(A). Grooving is generally caused by the buckling action of the plates when under pressure. It takes place chiefly around joints in the boiler-plate and in places where the scale has become cracked. The following figure shows an example of grooving(B).

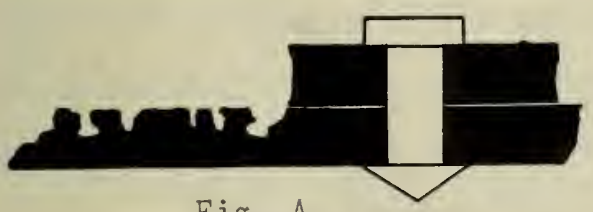

Fig. A.

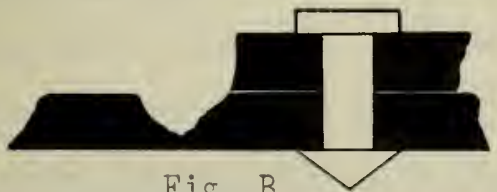

Fig. B.

FOAMING.

Foaming is the result of dirty or greasy water in the boiler, and occurs when the water froths at the surface. Alkalies when present to a great extent in water cause foaming. The chief objection to foaming is that it causes wet steam, which lowers the efficiency of the boiler. It may also cause a wrong water level reading in the gauge glass which will produce, due to insufficient amount of water, overheating of the boiler plates. Foaming is not as troublesome in stationary as in locomotive boilers. 100 grains per gallon of foaming constituents is considered the critical point for the latter.*

*Report of Com., Am.Ry.Eng. & Maintenance of Way Ass. Bull. 83,p.45.

To overcome the abovementioned objections in water several methods of treatment have been put into use. The water may either be treated in or out of the boiler. The latter method is the most desirable, for the wear on the boiler is increased by causing chemical reactions to take place in it. But the cost of installing an outside treatment plant is quite high, and most manufacturing concerns and heating plants running on a small scale, cannot afford them, so they rely on the treatment within the boiler. This latter phase of boiler-water treatment is the one taken up in this paper.

Many substances were used to bring about a better efficiency in the boiler. In Scotland potatoes were used to prevent the formation of scale.* In some places sand was used, it being thought that the scale would collect on this substance and not on the boiler.

*Western Railway Club - W. H. Edgar - p. 230.

In other places kerosene was used.* Some of these rather crude ma-

*Water Softening - Collet - p. 34.

terials gave good results, but it was found that certain chemicals when added to the water in the boiler gave more rapid, and sometimes better results. Some of them even prevented corrosion to some extent, a thing not produced by the cruder materials. These chemicals and mixtures were sold under the name of "Boiler Compounds".

An ideal "boiler compound" would be one that will prevent scaling, corrosion and foaming. None of the compounds manufactured so far have been able to prevent all of these reactions. In fact, a boiler compound must be made to fit each individual case.

The boiler compounds on the market are so many and so various, that it would be impossible to refer to one tenth of them. Most of them are valueless, but there are a few which give very excellent results. The most commonly used of these is sodium carbonate(Na_2CO_3). The great majority of the better compounds contain this chemical in a large proportion. Its action is purely chemical, not mechanical, and its usefulness depends upon its ability to change the sulphates of calcium and magnesium to the carbonates. The reactions are as follows:-

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$$

$$MgSO_4 + Na_2CO_3 = MgCO_3 + Na_2SO_4$$

$$MgCl_2 + Na_2CO_3 = MgCO_3 + 2NaCl$$

It also aids the precipitation of the carbonates present. Too much of it, however, causes foaming.

Caustic soda(NaOH) acts in much the same way as the carbonate, its only disadvantage is that it is very corrosive. It was

introduced as a boiler compound* by Dr. C. B. Dudley, Chemist for the Pennsylvania Railroad Company.

Tannin and tannate of sodium are frequently used. They act somewhat similar to soda in that they precipitate the calcium and magnesium. The tannic acid attacks the iron plates to a great extent and is therefore a very strong corrosive.* Good tannin com-

*Exam. of Water for San. and Tech. Purposes - Leffman - page 131.

pounds are much higher in cost than sodium carbonate, and are not as much used for that reason.

Tri sodium phosphate(Na_3PO_4) was introduced as a boiler compound by W. J. Williams of the Keystone Chemical Company, Camden, N. J. in 1888. Aside from its price, which is about nine times that of sodium carbonate, phosphate of soda has certain advantages. It produces by its action on lime salts in the water, flocculent, amorphous precipitates, which are absolutely nonadhering to the boiler surface, and are easily blown out.* In January 1899 Prof. C. F. Mabery and Ed. Baltzley called attention to the use of sodium aluminate(Na_2AlO_2) for removing scale-forming matter from water. This compound acts in the same manner as sodium hydroxide.*

*Trans. of Am. Soc. C. E., Vol. LIV, page 8 - J. O. Handy.

In America petroleum is being put into boilers to prevent scale. Its action is purely mechanical. It forms a coating of oil on the crystals which prevents them from cohering, but the effect is not lasting, because the oil soon passes off with the steam. The water in such cases is greasy and foams considerably.*

*Gebhardt - Steam Power Plant Engineering - page 213.

Hydrochloric acid has been used to eat off the scale, but in most cases the boiler plate is eaten away. It has to be added in measured quantities and even then it gives bad results. Ammonium chloride has been tried, but this substance has the same drawbacks that the acid has.*

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*International Correspondence Schools-pamphlet No. 358-page 38.

In 1890, in a paper before the American Chemical Society, Dr. Chas. A. Doremus talked of using sodium fluoride for a boiler compound. Its price is ten times as great as that of sodium carbonate, which acts in the same manner.*

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*Trans. Am. Soc. C. E., Vol. LIV - page 8 - J. C. Handy.

De La Coux recommends: Boil 2 kilograms of oak sawdust for an hour, at least, in 10 liters of water, then add 3 kilograms of molasses. A kilogram of this compound per H.P. per week is usually sufficient.*

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*Boiler Waters - Christie - page 15.

The Chicago, Milwaukee and Saint Paul railroad uses for the surface waters in the forest region of Wisconsin at Wauvau, the following compound: One part of caustic soda and one-half part of sodium carbonate.*

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*Boiler Waters - Christie - page 213.

Some compounds now in use and their composition are:-

1. "Arcanum". Na_2CO_3, 11.6%; NaCl, 1.24%; Fe, Al, Ca, Mg, 0.7%; Organic matter 1.86%; water 84%. +

2. "Séfénifuge". Na_2CO_3 and sugar.+

3. "Anti-Tartré-Végétal-Bretal". 10% solution of organic substances.+

4. "Anticarbonit". Tar dyes; Na_2CO_3, 23%; $NaHCO_3$, 62%; $CaCO_3$, 2.5%; NaCl, Na_2SO_4 and water.+

5. "Sélénige". Soda and Molasses.+

+Biedermann's Technique Chemisches Jahrbuch - Hagedorn - page 303.

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6. "Tannate". Sodium tannate, 10%; tannin extract containing saccharine and general inert matter of the extract, 60%; mixture of cane and grape sugar with some soluble starch, 10%.*

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*Western Railway Club - W. H. Edgar - page 231.

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7. "Compound No. 1". Sawdust, Na_2CO_3 and some sulphates.*

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*Analysis by Department of Applied Chemistry, University of Illinois.

From this we see that the composition of the various compounds is quite different and it is seldom if ever that the name represents the content, in fact cases are known where Lake Michigan water has been sold for a boiler compound.* It is the intention of

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*Western Railway Club - G. M. Davidson - page 247.

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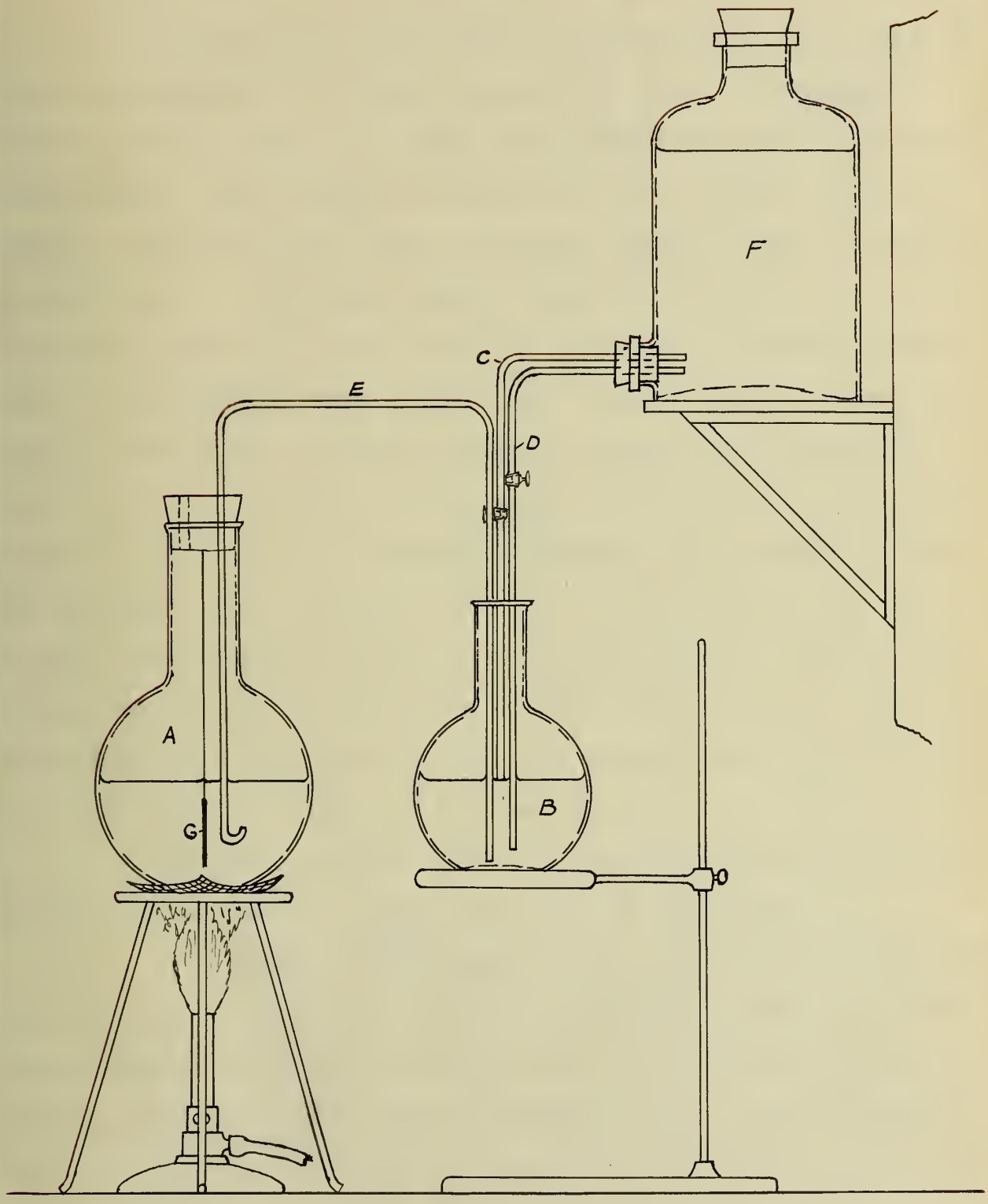
the author to give the important compounds used in boilers a thorough test, and find out their good and bad qualities.



Automatic Constant Level Apparatus.

EXPERIMENTAL WORK.

In order to bring about the reactions in the boiler as near as possible the following method was used: (See Chart I.) The water to be tested is placed in a tubulated bottle to serve as a reservoir(F). The tubulus is fitted with two tubes(C) and (D), one shorter than the other, which dip into a small flask(B), placed at a lower level.. From this flask a siphon(E) runs over to a heating flask(A), placed on a level with the flask(B). Into the flask(A) a sheet of iron(G) is hung. After once filling the reservoir, the level of the water in flask A remains automatically constant, for as soon as any water boils off in A and the level lowers, the siphon draws over some of the water from flask B, which lowers the level in the latter. Tube C being shorter than D allows air to go up through it into the reservoir, which is air tight, and water flows down through C until the water level is high enough to seal D again. In this manner the experiment can be started and kept running without much watching on the part of the manipulator.

As large amounts of water were needed, the University of Illinois water was used most frequently in the tests.

The flask(A) was weighed before and after the experiment. Any increase in the weight of the flask gave the amount of scale-forming material deposited on the walls. The flask was shaken thoroughly, and washed with distilled water so that soluble deposits, which would be carried away by the blowing off of the boiler, would not enter into the increase in weight.

The piece of sheet iron(G) was weighed before putting into the flask, and after the boiling was completed, it was

thoroughly washed and cleaned with fine pumice stone. This latter cleaner was used because in the highly scaling waters a small amount of scale formed on the sheet. It was then dried with alchol and ether and was placed in a dessicator until ready to weigh. Any loss in the weight of the iron gave the amount of iron eaten away or corroded. It was thought that perhaps some of the iron was removed by the pumice so a blank test was run. The following results were obtained:-

Number of Strokes.	Iron Lost. 1	2	Mean.
10	.0003gm.	.0005gm.	.0004gm.
20	.0006 "	.0007 "	.00065"
30	.0007 "	.0009 "	.0008 "
40	.0010 "	.0013 "	.00115"
50	.0017 "	.0015 "	.0016 "

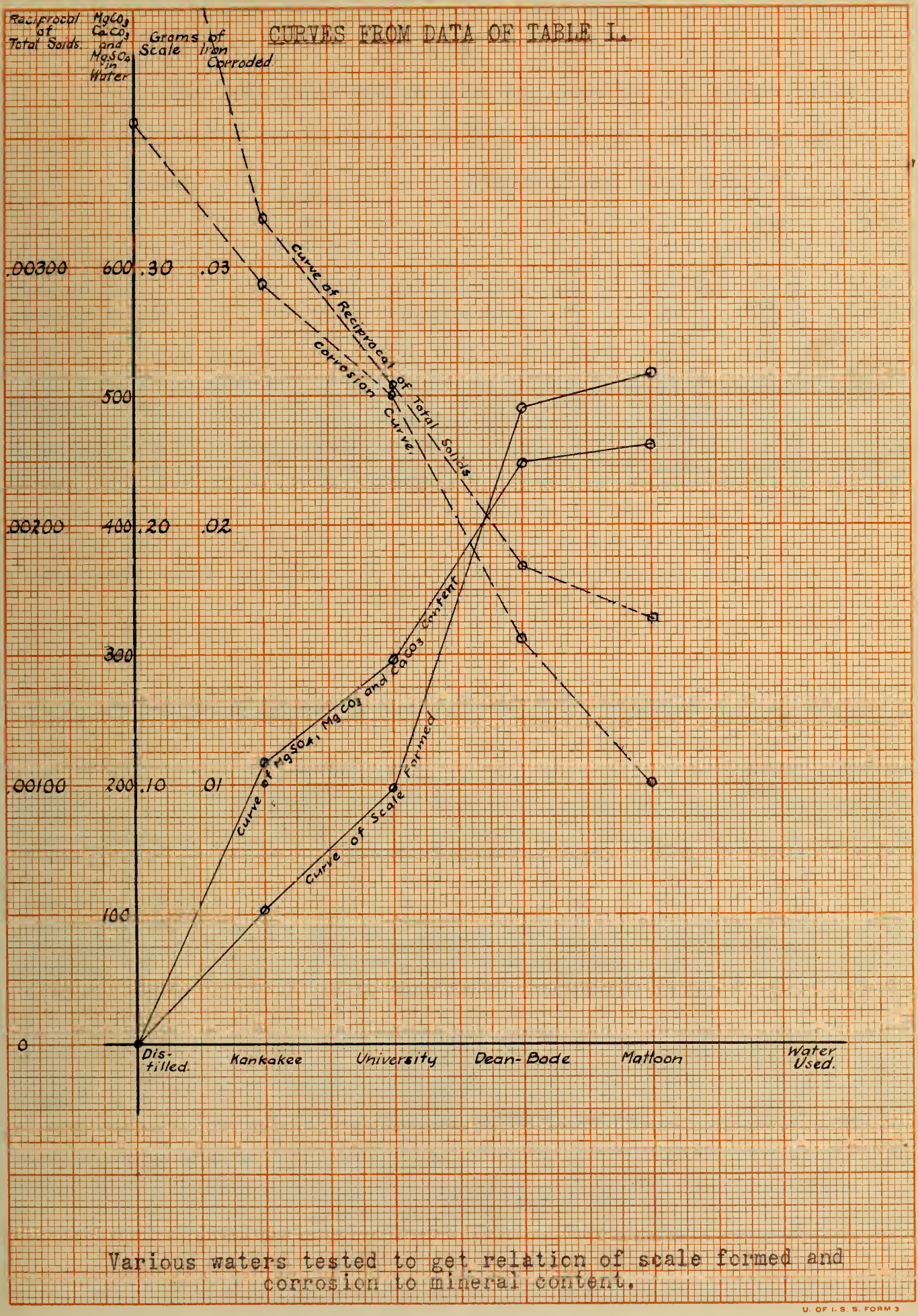
The loss due to 50 strokes was used as a correction in drawing the curves.

The following tables give some of the results obtained.

TABLE I.

Boiling down of two liters of various waters to 500 cubic centimeters

Iron Corroded.	Scale Formed.	Source of Water.
.0156gm.	.2461gm.	Dean - Bode Mfg. Co., Champaign.
.0293 "	.1012 "	Kankakee River Water.
.0100 "	.2578 "	Mattoon City Supply.
.0362 "	.0000 "	Double-distilled.
.0250 "	.1979 "	University Supply.
.0330 "	.0000 "	Distilled Water.



Various waters tested to get relation of scale formed and corrosion to mineral content.

U. OF I. S. S. FORM 3

The following tables give analyses of the waters used.

Analysis*of water from Dean-Bode Mfg., Co., Champaign, Ill.

Ions		Parts per Million	Hypothetical Combinations		Parts per Million	Grains per Gallon
Sodium Na		33.4	Sodium nitrate	$NaNO_3$	1.6	0.09
Magnesium Mg		50.0	Sodium chloride	NaCl	39.6	2.31
Calcium Ca		106.9	Sodium sulphate	Na_2SO_4	53.7	3.13
Oxides of Iron and Alumina	Fe_2O_3+ Al_2O_3	2.2	Magnesium sulphate	$MgSO_4$	145.7	8.49
Nitrate NO_3		1.2	Magnesium carbonate	$MgCO_3$	36.4	2.12
Chloride Cl		24.0	Calcium carbonate	$CaCO_3$	266.8	15.56
Sulphate SO_4		152.5	Oxides of Iron and Alumina	Fe_2O_3+ Al_2O_3	2.2	0.13
Silica SiO_2		11.0	Silica	SiO_2	11.0	0.64
Bases		3.0	Bases	----	3.0	0.17
			Total Mineral Matter		560.0	32.64

*Municipal Water Supplies of Illinois - Bulletin No. 5, of the Illinois State Water Survey.

Analysis*of Kankakee River Water from Kankakee, Illinois.

Ions		Parts per Million	Hypothetical Combinations		Parts per Million	Grains per Gallon
Potassium K		2.0	Potassium nitrate	KNO_3	5.2	0.30
Sodium Na		5.3	Sodium nitrate	$NaNO_3$	2.9	0.17
Ammonium (NH_4)		.1	Sodium chloride	NaCl	3.3	0.19
Magnesium Mg		17.6	Sodium sulphate	Na_2SO_4	9.9	.58
Calcium Ca		56.7	Ammonium sulphate	$(NH_4)_2SO_4$	.4	.02
Ferrous Fe		4.2	Magnesium sulphate	$MgSO_4$	53.9	3.14
Alumina Al_2O_3		10.8	Magnesium carbonate	$MgCO_3$	23.2	1.35
Silica SiO_2		37.2	Calcium carbonate	$CaCO_3$	141.5	8.25
Nitrate NO_3		5.3	Ferrous carbonate	$FeCO_3$	8.1	.51
Chloride Cl		2.0	Alumina	Al_2O_3	10.8	.63
Sulphate SO_4		50.0	Silica	SiO_2	37.2	2.17
Bases		16.5	Bases	----	16.5	.96
			Total Mineral Matter		313.5	18.27

*"Municipal Water Supplies of Illinois" - Bulletin No. 5, of the Illinois State Water Survey.

Analysis* of Mattoon water from city Supply, Mattoon, Ill.

Ions	Parts per Million	Hypothetical Combinations		Parts per Million	Grains per Gallon
Potassium K	4.6	Potassium nitrate	KNO_3	1.1	.06
Sodium Na	42.2	Potassium chloride	KCl	7.9	.46
Ammonium (NH_4)	.5	Sodium chloride	NaCl	.8	.05
Magnesium Mg	49.5	Sodium sulphate	Na_2SO_4	129.4	7.55
Calcium Ca	93.6	Ammonium sulphate	$(NH_4)_2SO_4$	1.8	.10
Ferrous Fe	.4	Magnesium sulphate	$MgSO_4$	190.2	11.09
Alumina Al_2O_3	.8	Magnesium carbonate	$MgCO_3$	39.1	2.27
Silica SiO_2	13.9	Calcium carbonate	$CaCO_3$	233.9	13.64
Nitrate NO_3	.7	Ferrous carbonate	$FeCO_3$	.8	.05
Chloride Cl	4.2	Alumina	Al_2O_3	.8	.05
Sulphate SO_4	240.3	Silica	SiO_2	13.9	.81
		Total Mineral Matter		619.7	36.13

*Municipal Water Supplies of Illinois - Bulletin No. 5, of the Illinois State Water Survey.

Analysis* of water from the University of Illinois Supply.

Ions	Parts per Million	Hypothetical Combinations		Parts per Million	Grains per Gallon
Potassium K	2.6	Potassium nitrate	KNO_3	1.1	.06
Sodium Na	29.0	Potassium chloride	KCl	2.9	.17
Ammonium (NH_4)	2.3	Sodium chloride	NaCl	3.5	.20
Magnesium Mg	34.9	Sodium sulphate	Na_2SO_4	3.6	.21
Calcium Ca	70.1	Sodium carbonate	Na_2CO_3	60.5	3.52
Iron Fe	1.0	Ammonium carbonate	$(NH_4)_2CO_3$	6.1	.36
Aluminium Al	1.3	Magnesium carbonate	$MgCO_3$	121.2	7.07
Nitrate NO_3	.7	Calcium carbonate	$CaCO_3$	175.2	10.22
Chlorine Cl	3.5	Ferrous carbonate	$FeCO_3$	2.1	.12
Sulphate SO_4	2.3	Alumina	Al_2O_3	2.5	.15
Silica SiO_2	18.9	Silica	SiO_2	18.9	1.10
		Total Mineral Matter		397.6	23.18

*"Chemical and Biological Survey of the Waters of Illinois", Bulletin No. 6, of the Illinois State Water Survey.

The scale formed varies with the amount of $CaCO_3$, $MgSO_4$, and $MgCO_3$, as can be seen from the composition of the waters and Plate I. The corrosion varies inversely as the amount of solid matter in solution. Distilled waters are corrosive because of their tendency to satisfy their solubility properties.

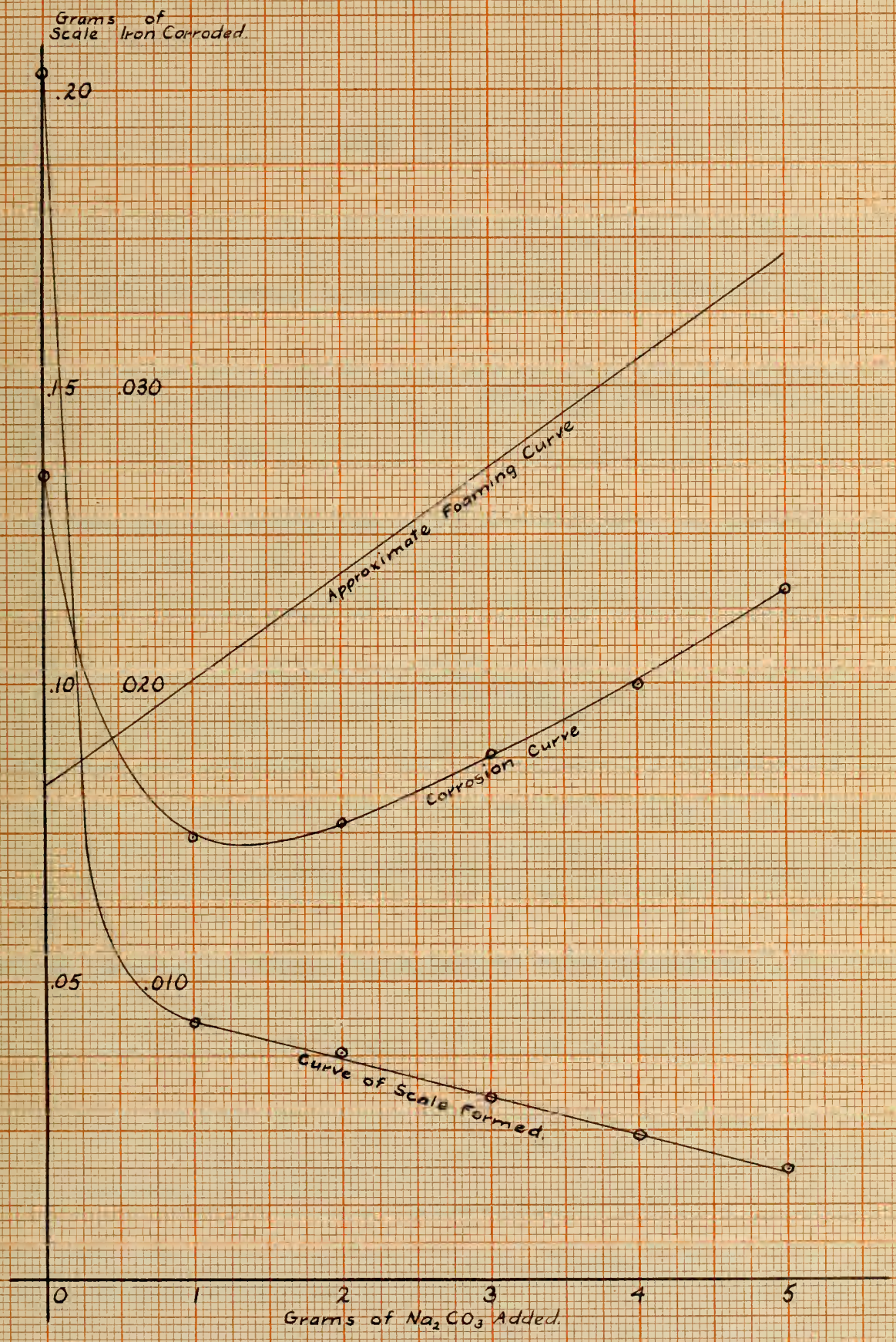
TABLE II.

Treatment of University water with Na_2CO_3. Two liters of the cold water were treated. Boiled down to 500 c.c.

Amount of Na_2CO_3 added.	Iron Corroded.	Scale Formed.	Foaming.
1 gm.	.0148 gm.	.042 gm.	high
2 "	.0152 "	.038 "	"
3 "	.0178 "	.030 "	"
4 "	.0186 "	.026 "	"
5 "	.0231 "	.018 "	"
untreated.	.0266 "	.206 "	very low

From this table it can be seen that the corrosion is somewhat lowered as well as the scale formation, but the foaming is increased to a most undesirable extent. The increased treatment, however, tends to increase the corrosive powers of the water.

CURVES FROM DATA OF TABLE II.



Treatment of University water with Sodium Carbonate (water cold).

U. OF I. S. S. FORM 3

TABLE III.

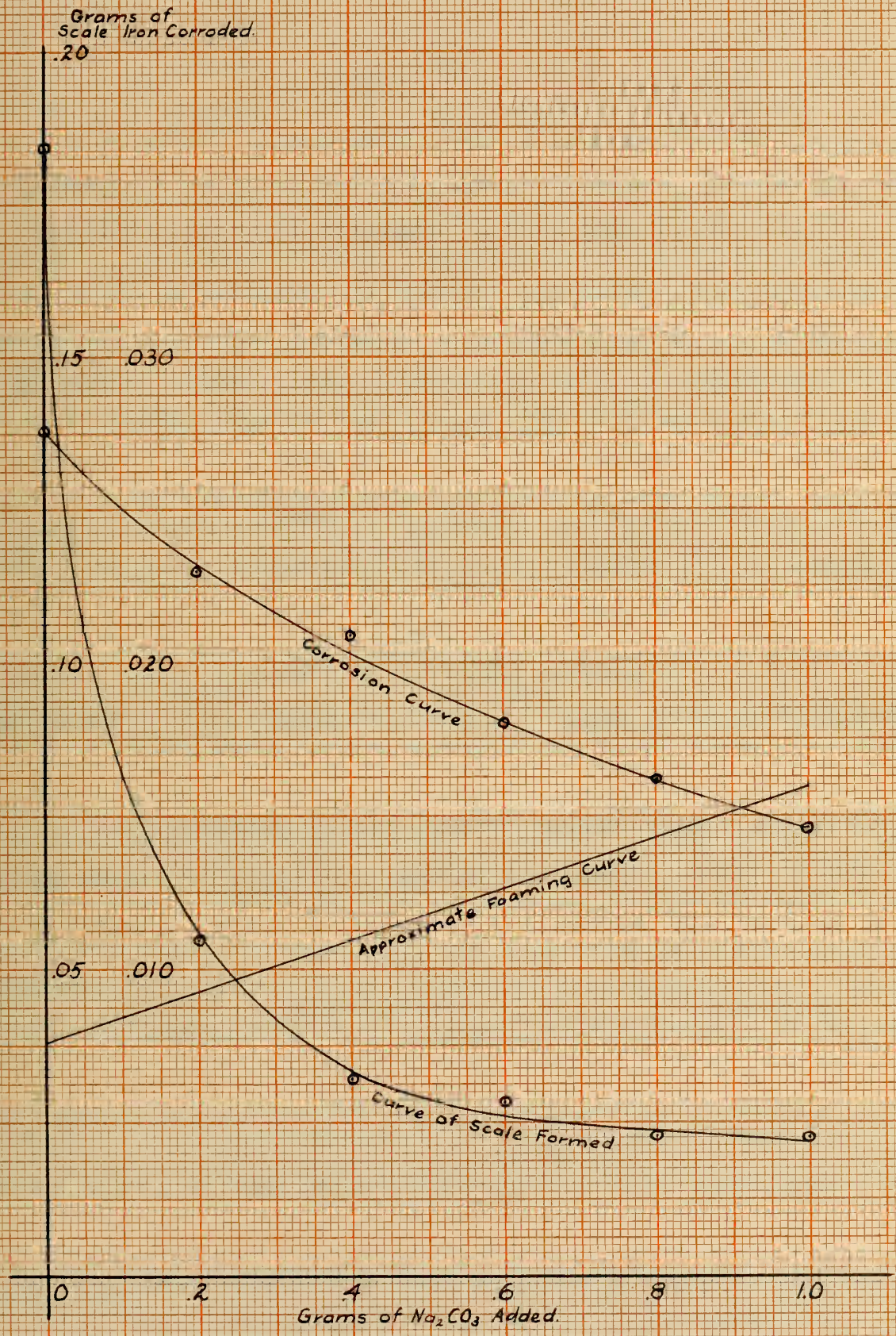
Treatment of University water with Na_2CO_3. Two liters of the hot water were treated. Boiled down to 500 c.c.

Amount of Na_2CO_3 added.	Iron Corroded.	Scale Formed.	Foaming.
.2 gm.	.0226 gm.	.054 gm.	slight
.4 "	.0209 "	.032 "	"
.6 "	.0180 "	.029 "	high
.8 "	.0161 "	.022 "	"
1.0 "	.0148 "	.023 "	"
untreated.	.0276 "	.184 "	very low

The corrosion is lowered as in Table II, although the scale formed is lower and the foaming less. However, the results are not as good as is desired for boiler water purposes.

PLATE III.

CURVES FROM DATA OF TABLE III.



Treatment of University water with Sodium Carbonate (water hot).

U. OF I. S. FORM 3

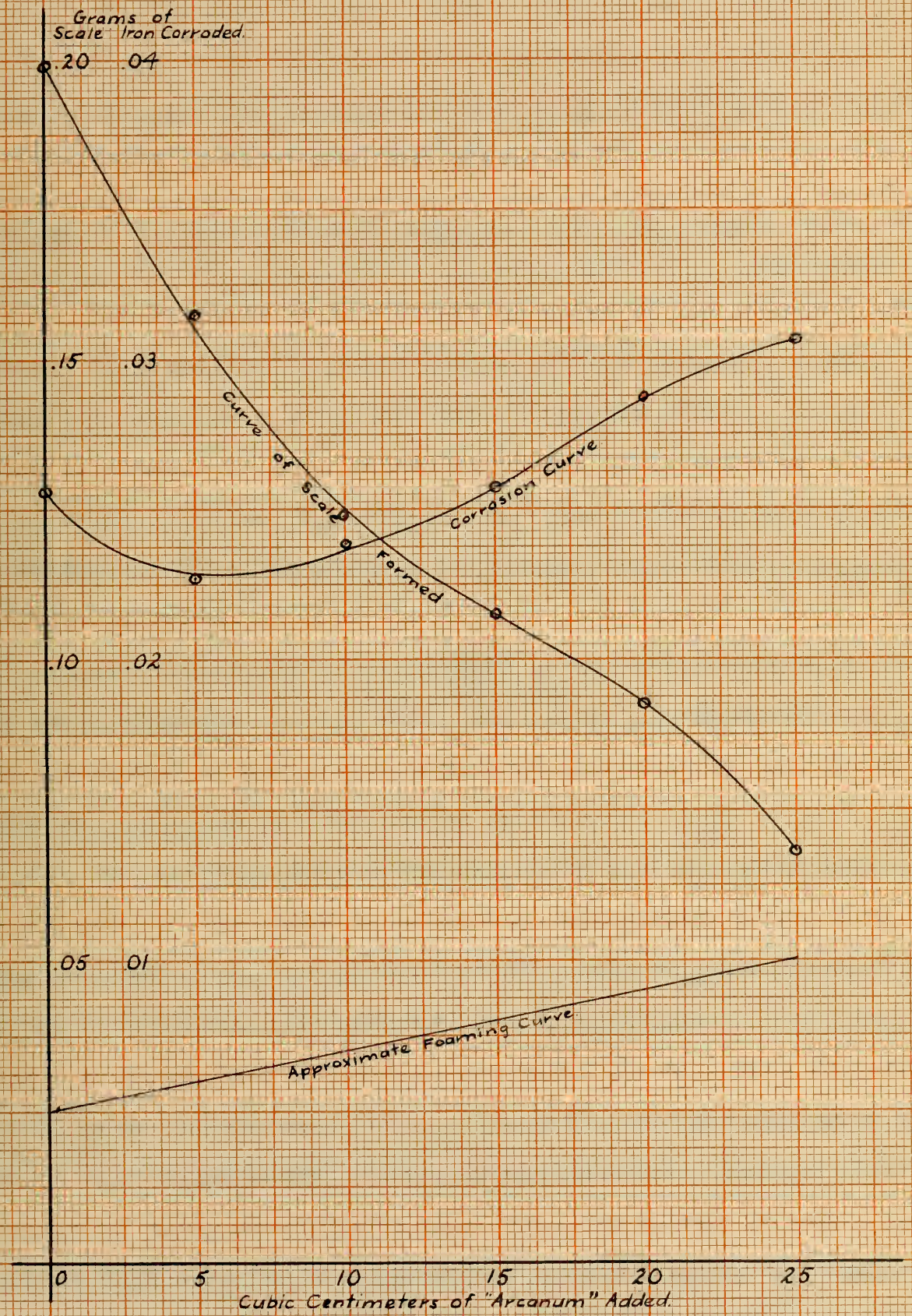
TABLE IV.

Treatment of University water with "Arcanum." Two liters of the hot water were treated. Boiled down to 500 c.c.

Amount of "Arcanum" added.	Iron Corroded.	Scale Formed.	Foaming.
5 c.c.	.0227 gm.	.158 gm.	slight
10 "	.0238 "	.112 "	"
15 "	.0252 "	.108 "	high
20 "	.0291 "	.094 "	"
25 "	.0305 "	.068 "	"
untreated.	.0256 "	.199 "	very low

The corrosion is not lowered appreciably. The scale formed is almost unchanged in smaller treatments, while in the higher treatments, where a change is noticeable, the foaming is too great.

CURVES FROM DATA OF TABLE IV.



Treatment of University water with "Arcanum". (water hot).

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At this stage it was thought best to run a rapid boiler water test in addition to the other so as to get the connection of the two. This test consists of the following determinations: Hardness, Alkalinity, Incrustants, and Magnesium.*

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*See Standard Methods of Water Analysis. page 55 - 66.

The hardness is determined by means of the standard soap solution. This solution is standardized with a standard calcium chloride solution and a curve for the standardization of the soap solution is drawn. 10 c.c. of the water are taken and soap solution is added until a lather forms which lasts for at least five minutes. By reference to the curve already mentioned, the hardness is parts per million is found.

The alkalinity is determined by titration with N/50 sulphuric acid. 100 c.c. of the water are generally used. By multiplying the number of cubic centimeters of acid used by ten the alkalinity in parts per million can be found.

The incrustants are determined in the following manner: Place 200 c.c. of the water in a 500 c.c. Erlenmeyer flask, boil 15 minutes to expel CO_2. Add 25 c.c. of N/20 soda reagent(composed of equal parts of sodium hydroxide and sodium carbonate). Boil ten minutes and filter into a 200 c.c. graduated flask. Fill this with distilled water to the mark, and use 50 c.c. for titration with N/50 sulphuric acid using methyl orange as an indicator. Make a blank determination using distilled water. Then the number of cubic centimeters of acid required to neutralize the blank minus the number required to neutralize the unknown gives the incrustants as $CaCO_3$.

This result multiplied by 20 gives the incrustants in parts per million. If the water contains Na_2CO_3 the blank determination will be less than that of the unknown.

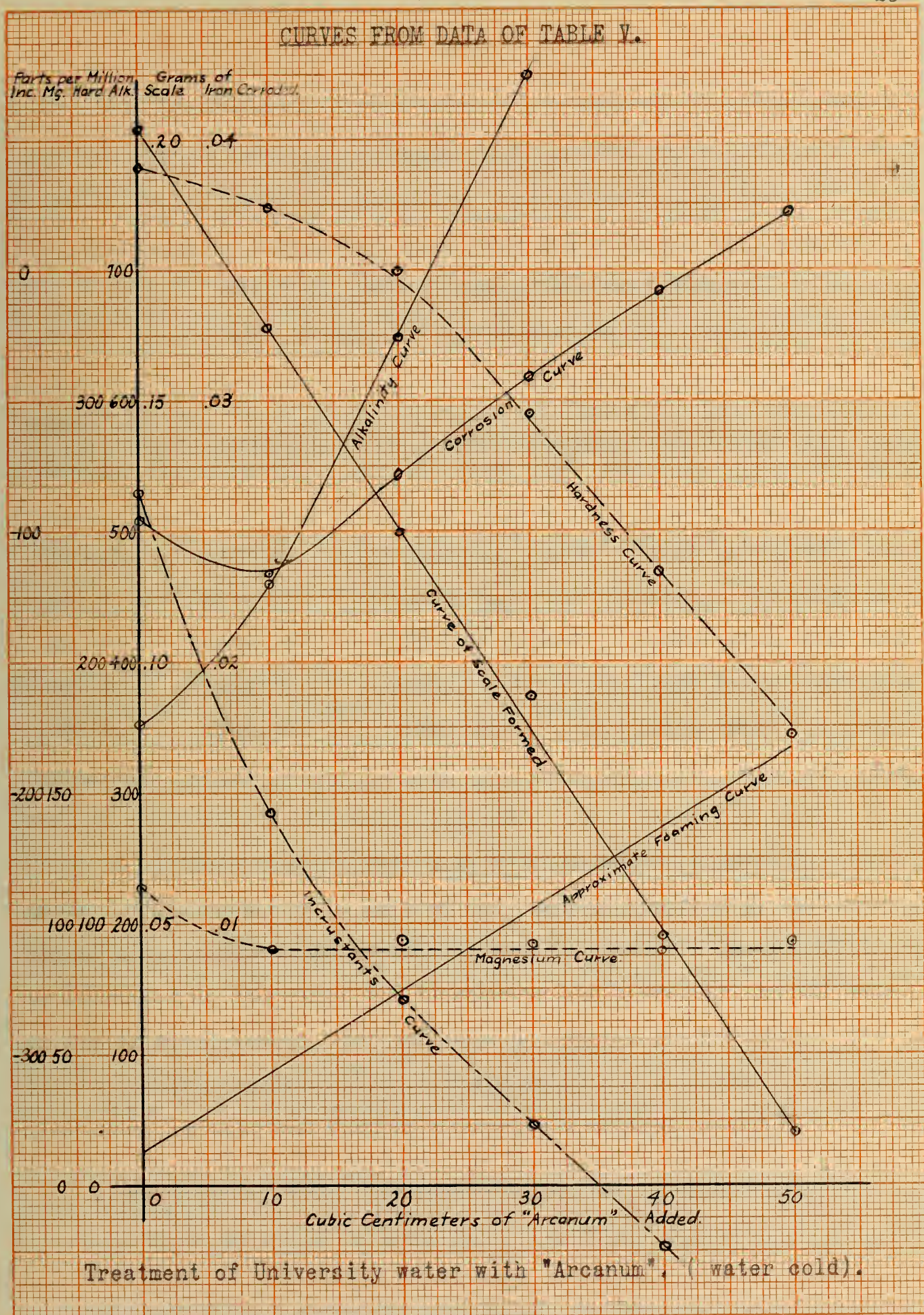
The magnesium is determined as follows: 100 c.c. of the water is neutralized with N/50 sulphuric acid using methyl orange as an indicator. (This will give the alkalinity). This is heated to expel the CO_2, in a 200 c.c. graduated flask. 25 or 50 c.c. of a saturated solution of lime water is added, and the whole is heated on the water-bath for 15 minutes. It is made up to 5 c.c. above the mark, shaken well and allowed to cool. Upon cooling the level will have fallen to the required mark. The excess of lime water is determined with N/50 sulphuric acid and using methyl orange as an indicator. 50 c.c. of the water is used for this purpose and a blank should always be run using distilled water. Use only the supernatent liquid. The blank determination minus the determination of the unknown gives the magnesium as $CaCO_3$. This result multiplied by 40 gives the magnesium (Mg) in parts per million.

TABLE V.

Treatment of University water with "Arcanum". Two liters of the cold water were treated. Boiled down to 500 c.c.

Amount of "Arcanum" added.	Iron Corroded.	Scale Formed.	Foaming.	Inc.	Mg.	Alk.	Hardness.
10 c.c.	.0231 gm.	.103 gm.	high	-207	88	462	375
20 "	.0279 "	.122 "	"	-282	104	644	350
30 "	.0301 "	.093 "	"	-327	96	844	295
40 "	.0346 "	.046 "	"	-372	80	1094	235
50 "	.0372 "	.009 "	"	-407	104	1296	170
untreated	.0253 "	.206 "	very low	-82	112	348	390

The corrosion is increased considerably. The scale formed is lowered, and decreases with the treatment. Foaming, however, is too great for all practical purposes.



Treatment of University water with "Arcanum", (water cold).

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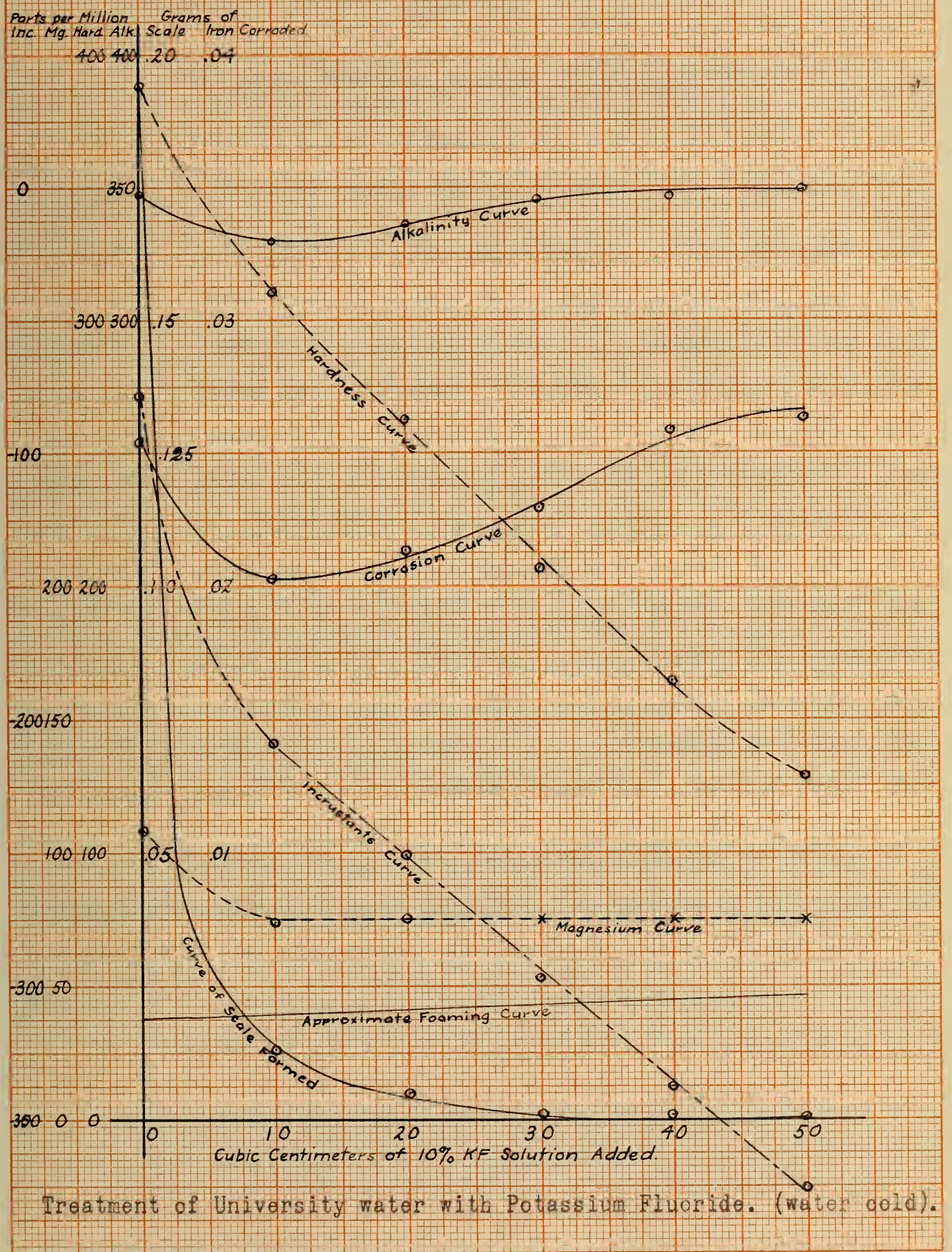
TABLE VI.

Treatment of University water with 10% solution of potassium fluoride. Two liters of the cold water were treated. Boiled down to 500 c.c.

Amount of fluoride added.	Iron Corroded.	Scale Formed.	Foaming.	Inc.	Mg.	Alk.	Hardness.
10 c.c.	.0202 gm.	.012 gm.	low	-210	73	332	310
20 "	.0216 "	.004 "	"	-250	75	335	265
30 "	.0229 "	.001 "	"	-298	over	347	205
40 "	.0256 "	.000 "	"	-337	treat-	347	165
50 "	.0262 "	.000 "	"	-376	ment	347	130
untreated	.0251 "	.194 "	very low	-79	114	347	385

The corrosion increases with increased treatment. The amount of scale formed is lowered and foaming practically unchanged. The 20 c.c. treatment gives the minimum Mg. result. The alkalinity is decreased in the first two treatments but after that is the same as the original water. The hardness is lowered considerably. The over treatment could be told by the precipitation of the excess of lime water so that one drop of acid gave a neutral result.

CURVES FROM DATA OF TABLE VI.



Treatment of University water with Potassium Fluoride. (water cold).

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TABLE VII.

Treatment of University water with Na_2CO_3. 3.5 liters of cold water treated. 500c.c. used up in making determinations and rest boiled to 500c.c.

Test A.

Amount of Na_2CO_3 added.	Iron Corroded.	Scale Formed.	Foaming.	Inc.	Mg.	Alk.	Hardness.
.2 gm.	.0327 gm.	.224 gm.	slight	-130	76	408	365
.4 "	.0338 "	.200 "	high	-178	72	412	345
.6 "	.0352 "	.157 "	"	-222	76	426	330
.8 "	.0391 "	.132 "	"	-278	75	448	315
1.0 "	.0402 "	.121 "	"	-322	80	472	300
untreated	.0384 "	.317 "	very low	-77	110	356	390

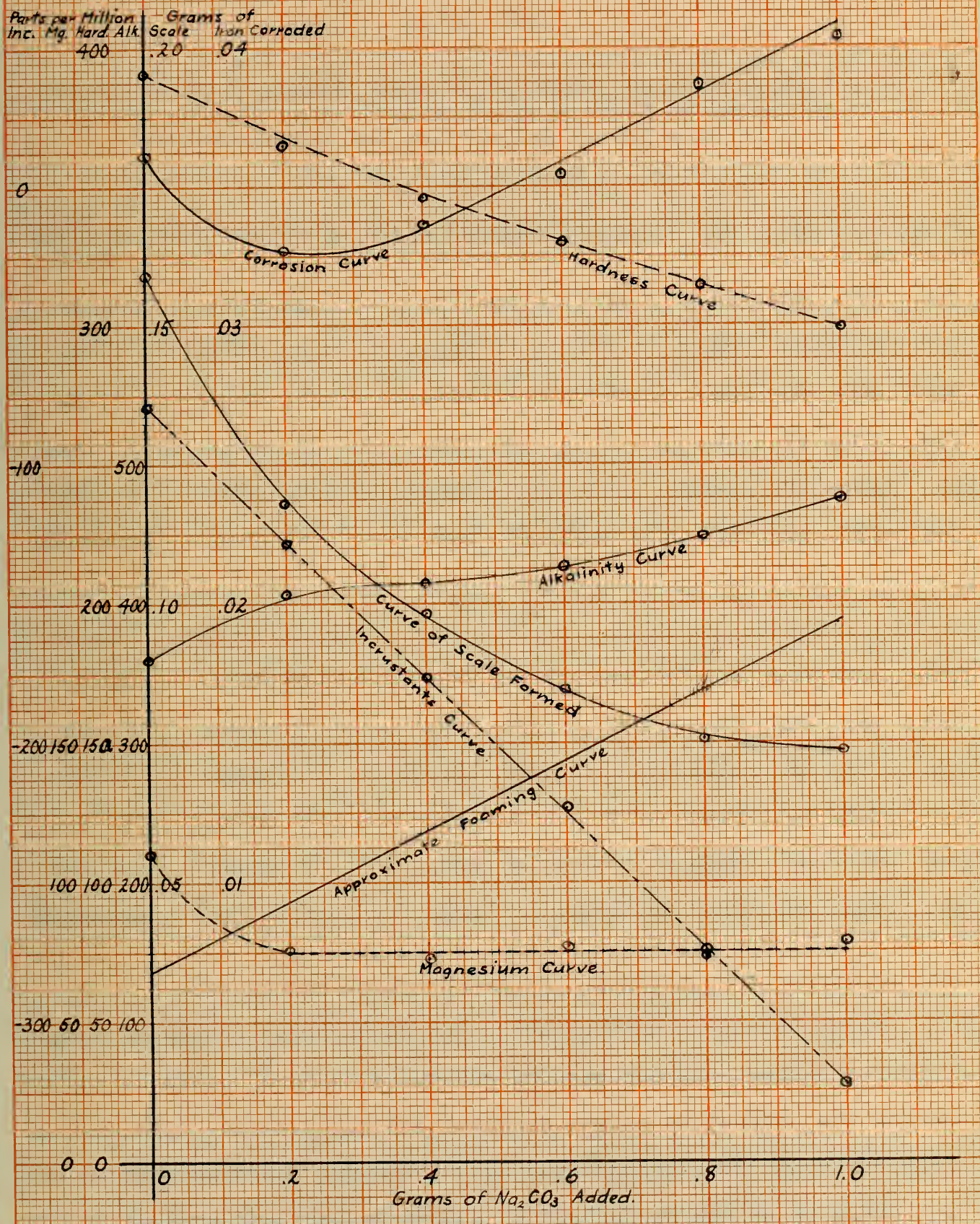
Test B.

.2 gm.	.0330 gm.	.218 gm.	slight	-132	78	412	360
.4 "	.0335 "	.201 "	high	-176	80	417	345
.6 "	.0357 "	.163 "	"	-220	79	430	325
.8 "	.0380 "	.152 "	"	-281	75	453	320
1.0 "	.0412 "	.126 "	"	-330	78	476	310
untreated	.0390 "	.303 "	very low	-82	116	354	385

The corrosion increases with the treatment (see Table II.) although the scale forming is lowered. The foaming is also high, and increased with the alkalinity. The hardness is not changed very much.

PLATE VII.

CURVES FROM DATA OF TABLE VII.



Treatment of University water with Sodium Carbonate. (water cold).

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TABLE VIII.

Treatment of University water with Sumach Extract(Tannin) 3.5 liters of cold water treated. 500c.c. used up in making determinations and rest boiled to 500 c.c.

Test A.

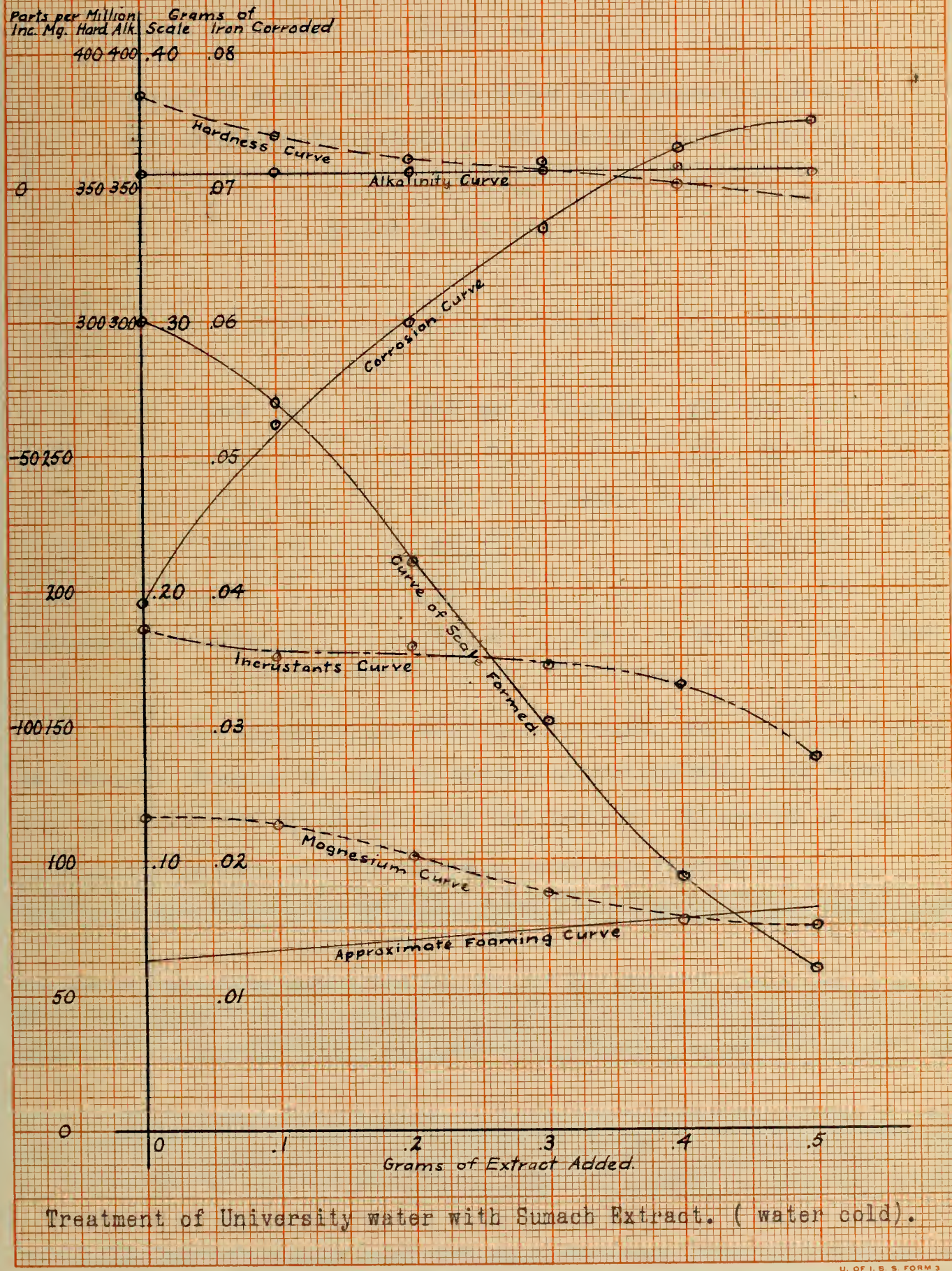
Amount of Extract added.	Iron Corroded.	Scale Formed.	Foaming.	Inc.	Mg.	Alk.	Hardness.
.1 gm.	.0570 gm.	.271 gm.	low	-88	108	353	365
.2 "	.0598 "	.206 "	"	-86	98	355	360
.3 "	.0667 "	.149 "	"	-88	84	354	355
.4 "	.0744 "	.083 "	"	-92	78	353	350
.5 "	.0747 "	.052 "	"	-108	73	353	345
untreated	.0386 "	.299 "	very low	-82	112	353	380

Test B.

.1 gm.	.0523 gm.	.276 gm.	low	-84	114	356	370
.2 "	.0592 "	.212 "	"	-78	100	356	360
.3 "	.0638 "	.153 "	"	-84	86	353	360
.4 "	.0702 "	.094 "	"	-90	79	355	350
.5 "	.0720 "	.061 "	"	-100	76	358	345
untreated	.0380 "	.304 "	very low	-82	118	355	385

The corrosion increases very rapidly, the amount in the higher treatment being about twice that of the untreated water. The amount of scale formed is lowered and the foaming remains practically unchanged. Alkalinity and hardness remain unchanged, and Magnesium is lowered only slightly. From the results obtained after heating it appears that decomposition of the tannin has taken place.

CURVES FROM DATA OF TABLE VIII.



Treatment of University water with Sumach Extract. (water cold).

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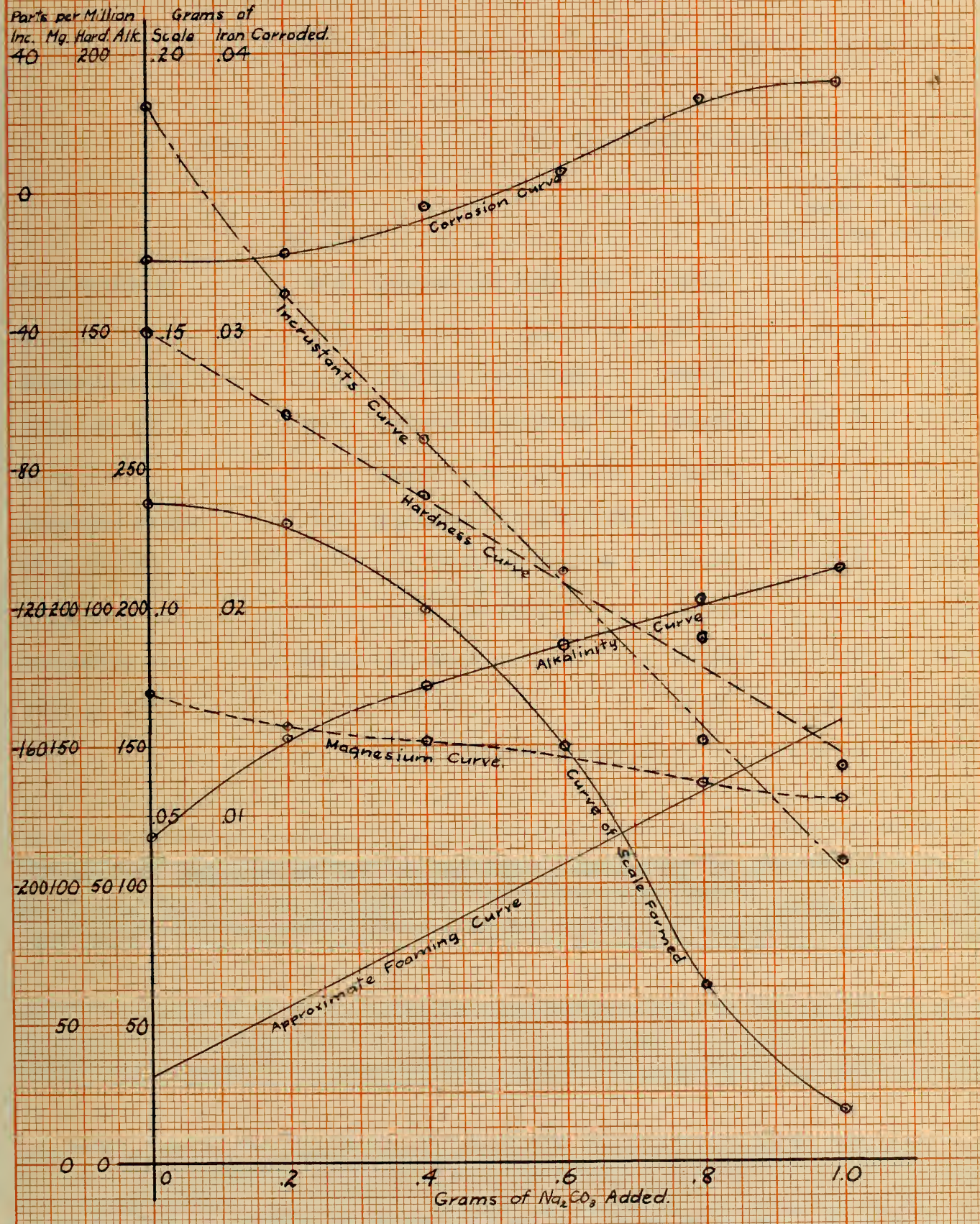
TABLE IX.

Treatment of Mississippi River water from Quincy, Illinois, with Na_2CO_3. 3.5 liters of cold water treated. 500c.c. used up in making determinations and remainder boiled to 500 c.c.

Amount of Na_2CO_3 added.	Iron Corroded.	Scale Formed.	Foaming.	Inc.	Mg.	Alk.	Hardness.
.2 gm.	.0326 gm.	.116 gm.	slight	-30	156	164	135
.4 "	.0343 "	.099 "	"	-72	152	170	120
.6 "	.0356 "	.075 "	high	-110	148	183	100
.8 "	.0383 "	.031 "	"	-160	128	202	95
1.0 "	.0388 "	.009 "	"	-194	124	223	70
untreated	.0326 "	.119 "	low	24	168	116	150

The corrosion is slightly increased, and the scale formed is lowered. Foaming is high in the higher treatments. The alkalinity increases, and the incrustants are lowered. Magnesium is lowered to a slight extent, and the hardness decreases regularly.

CURVES FROM DATA OF TABLE IX.



Treatment of Mississippi River water with Sodium Carbonate. (water cold).

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Analysis of Mississippi River water at Quincy, Illincis.(Filtered)*

Ions	Parts per Million	Hypothetical Combinations		Parts per Million	Grains per Gallon
Potassium K	2.7	Potassium nitrate	KNO_3	4.9	.29
Sodium Na	4.3	Potassium chloride	KCl	1.5	.09
Magnesium Mg	9.3	Sodium chloride	NaCl	1.3	.08
Calcium Ca	18.4	Sodium sulphate	Na_2SO_4	11.7	.68
Iron Fe	.7	Magnesium sulphate	$MgSO_4$	30.5	1.78
Alumina Al_2O_3	1.2	Magnesium carbonate	$MgCO_3$	11.1	.05
Nitrate NO_3	3.0	Calcium carbonate	$CaCO_3$	45.9	2.08
Chloride Cl	1.5	Iron carbonate	$FeCO_3$	1.5	.09
Sulphate SO_4	32.3	Alumina	Al_2O_3	1.2	.07
Silica SiO_2	6.5	Silica	SiO_2	6.5	.38
		Total Mineral Matter		116.1	6.79

*Municipal Water Supplies of Illinois - Bulletin No. 5, of the Illinois State Water Survey.

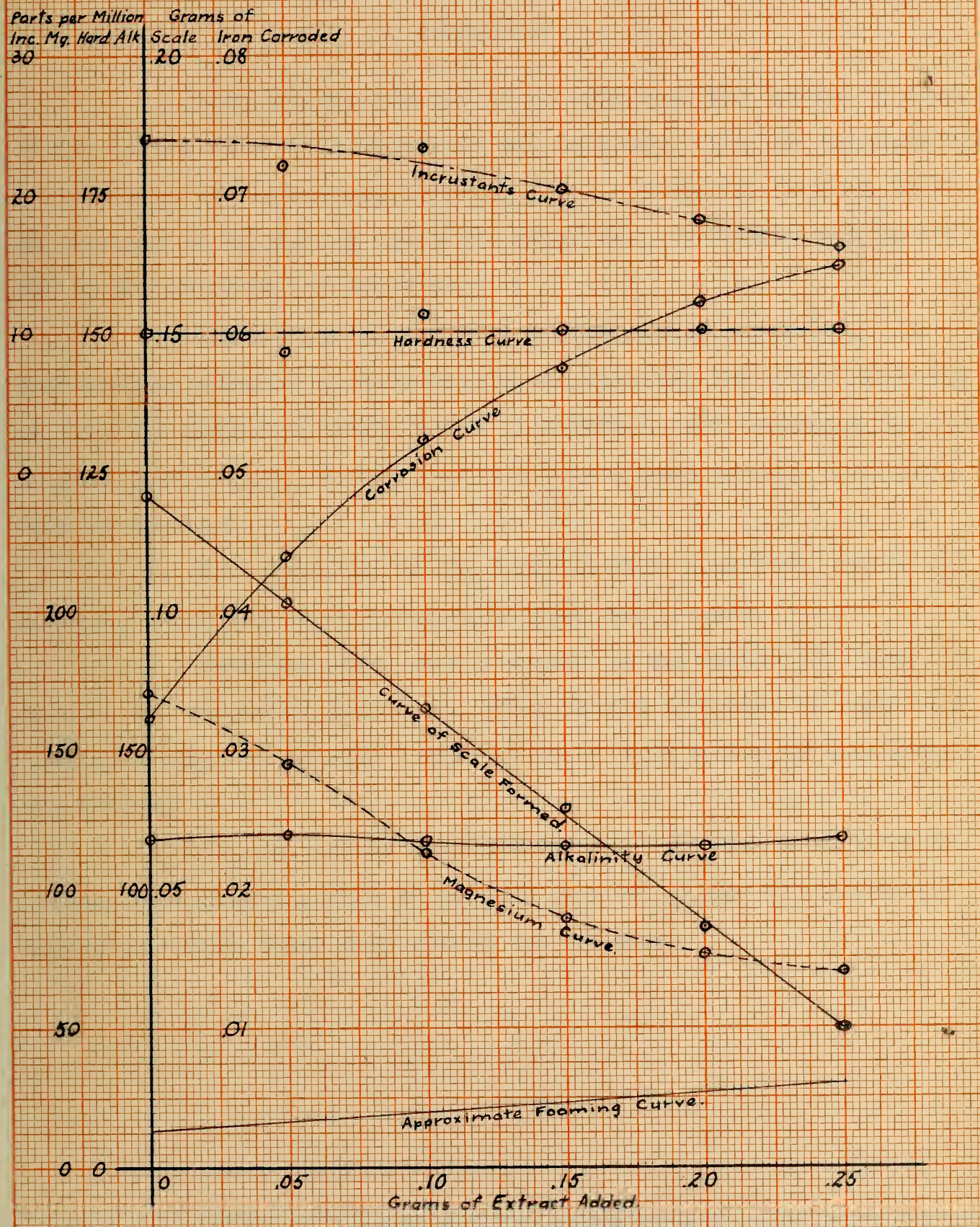
TABLE X.

Treatment of Mississippi River water, from Quincy, Illinois, with Sumach Extract. 3.5 liters of cold water treated. 500 c.c. used for making determinations and the remainder boiled to 500 c.c.

Amount of Extract added.	Iron Corroded.	Scale Formed.	Foaming.	Inc.	Mg.	Alk.	Hardness.
.05 gm.	.0541 gm.	.102 gm.	low	22	145	116	150
.1 "	.0525 "	.085 "	"	23	103	118	145
.15 "	.0570 "	.063 "	"	20	88	117	155
.20 "	.0620 "	.041 "	"	18	75	116	150
.25 "	.0648 "	.026 "	"	16	70	115	150
untreated	.0322 "	.121 "	"	24	168	116	150

The corrosion increases very rapidly. The amount of scale formed is lowered, and the foaming remains almost unchanged. Alkalinity, hardness, and magnesium are practically constant. The results of corrosion and amount of scale formed indicate that some decomposition of the tannin has taken place after heating.

CURVES FROM DATA OF TABLE X.



Treatment of Mississippi River water with Sumach Extract. (water cold).

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CONCLUSION.

1. From the experiments it is seen that the amount of scale formed varies with the incrustants and hardness, with the hardness in particular. The corrosion varies with the alkalinity, showing that an increase in alkalinity makes the water more corrosive, due probably to the formation of hydrates.

2. The waters treated with sumach are an exception. In such waters, alkalinity, incrustants and hardness are almost unchanged, but the amount of scale formed is lowered. The corrosion increases continually, showing that the tannin must undergo decomposition on heating.

3. The magnesium in all cases reaches a minimum, which is, however, above the point of solubility of the hydrate.

4. Wherever there is a decrease in the amount of scale formed, the corrosion increases. When sodium carbonate is used, the foaming becomes so prominent that it makes this method of treatment impractical.

5. In none of the experiments tried are the results ideal. Further experiments should be carried on with waters of a different character before final conclusions can be made.

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